On breathing and geography: explorations of data sonifications of timespace processes with illustrating examples from a tidally dynamic landscape (Severn Estuary, UK)

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Abstract. This paper consists of a discussion of data sonification—a procedure in which information gathered from systems such as bodies or environmental processes is analyzed and reprocessed into audio models, so aspects of the process generating the data (for example, emotional or tidal ebb and flow) can be apprehended by human senses. This serves various purposes relevant to geography. Firstly, it sets out the principles of sonification as a method, defining its basic principles and relating it to both qualitative and quantitative data. Secondly, it offers potential to geographic interests in process, times, rhythm, landscape, place, and more besides— 'representing' various aspects of processes that are beyond normal human apprehension, perhaps through register, duration, pitch, and so on. Thirdly, in the illustrating examples, which comprise sonifications of tides and other processes in the Severn Estuary, UK, it highlights possibilities of engaging local communities and stakeholders with the dynamics of landscapes such as tidal processes, which have significant implications for culture, economy, and ecology, as do other tidal and other process geographies elsewhere.

Keywords: sonification, process, rhythm, landscape, time, tides

> The Severn was brown and the Severn was blue—
> Not this-then-that, not either-or,
> No mixture. Two things can be true.
> The hills were clouds and the mist a shore.
> > extract from "Severn Song", *The Water Table*, Philip Gross (2009)

Introduction
This paper serves a number of purposes for geography and related disciplines. Primarily it sets out the principles of data sonification as a method of exploring processes in spacetime terrains such as bodies and landscapes. Data are routinely visualized in a range of diagrammatic forms (eg, graphs, bar and pie charts) and these are staple forms of scientific analysis and communication. Data sonification offers the chance of analyzing and communicating processes in very different ways. Firstly, sonification artefacts or events[1] retain temporal and performative dynamics within themselves as they play in time. Secondly, human affective

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[1] Sonification creations may be called 'artefacts' but also be termed 'events' as they take place in time when played/performed.

processing works very differently between the visual and the aural. We cannot fully explore these implications here (as it is such a vast subject), but we do point to how differently sight and hearing work as senses and to affective implications. One need only consider the form and power of music to begin to engage with the opportunities, and challenges, of sonification.

Sonification takes collected values from some process or other and, through various manipulations and recalibrations, creates an event that 'represents' some or other aspect of that process in ways amenable to immediate human perception. For example, the rise of CO_2 in the earth's atmosphere since the start of the industrial age (routinely represented by a graph) could be represented by a ten-minute (or other duration) sound event where changing note values and tempi represent the increase.

The world is a weave of processes—'a complex passing of events' (Whitehead, 1964, page 78). Current, dominant *visualizations* or processes struggle to appreciate this as we freeze the world, cut it up into objects for study, risking that the essence of life is lost. We hope that sonification can play a part in moving us to a more activist-based philosophy (Massumi, 2011) in which there are traces of creativity and nonrepresentation (Thrift, 2008).

In what follows we explore the above themes in more detail, then discuss examples of sonifications of a tidally dynamic landscape (the Severn Estuary, UK). Tidal landscapes are very obviously in motion all the time, articulated as complex sets of rhythmic flows generated by the spin of the earth and the relative motion of moon, earth, and sun. The complex interleaving patterns of daily, monthly, seasonal (and beyond) tide times and ranges, help shape the spacetimes not only of ecology and geomorphology but of a range of economic and cultural processes in the estuary and its hinterlands. Sonification and mapping techniques of data can deepen and intensify people's engagement with such nonhuman rhythms and temporalities in this case, as in a range of other terrains (from bodies to landscapes), and express the dynamism and vitality therein.

We feel that sonification has potential in just about any line of inquiry geographers and others might be pursuing. One final thing to say in this introduction is that writing representations of sonifications could be said to be defeating the aim; however, the prototype sonifications discussed in the paper, created by the authors and students at the University of the West of England, are online and can be accessed freely.

Life, processes, refrains (a call to arms)
A societal blindness to process (as opposed to objects) is highly problematic for the flourishing of diversity on earth. Ecocide (Guattari, 2000) is well underway. Lovelock has recently claimed that the current definitions of life embedded in the biological sciences are too narrow:

> "[Life as currently defined] must contain DNA, it must reproduce. I think it should encompass large entities like ecosystems. The atmosphere, the oceans, the first few miles of surface rock. As alive as the cells in your toes are alive, and part of you, and you are alive" (Lovelock cited by Ferguson, 2009).

We need to develop greater sensitivities to the life-making processes of the biosphere, which might operate over eons and in the most 'mundane' of materials and registers: for example in erosion–deposition cycles.

Welland (2009) discusses the processes of rivers in the development of the biosphere as they transport 'sand' (sediment) and organic material from evolving land to evolving oceans over eons. He observes that "around a third of this natural volume is [now] prevented from reaching the oceans as a result of being trapped behind dams and other man-made obstructions" (page 81).

Other sand-created landscapes such as coastal dunes that slowly creep in the wind—with accompanying ecological and cultural rhythms/responses—are routinely fixed or eradicated by

land-use development. Indicative of process blindness is that sand dune conservation strategies in the UK have sought to fix such creeping landscapes. Over the last thirty years concerns for the loss of this type of geomorphological feature and its ecologies have led to various techniques of 'stabilization' including the planting of Marram grasses which tolerate such conditions and bind the sand with roots. However, conservation agencies are now recognizing that this method 'kills' the processes that the sand dunes actually are—their continuous reformation and migration in relation to wind-blow. So in some cases conservation agencies are removing areas of grass they had previously planted to set the processes going again. A similar move towards recognizing that (varying) process is a key part of living landscapes can been seen in efforts to 'rewild' rivers. This is not some sentimental return to the purity of nature. It is a recognition that rivers are complex processes over time that will move channel, flood, irrigate, and drain wetland areas, and so on, and that these processes are vital (literally) for flood management, habitat creation, carbon capture, and other 'ecosystem services'.

Enlightenment-derived modernist philosophy, culture, politics, and ethics have been a campaign of divide and (mis)rule. Relationalities and ecological processes are dismissed. The human body is an extraordinary ongoing process of exchange (breathing, intake of water and nutrients, and output of waste) and cohabitation, but yet we see ourselves as apart from and above 'nature'.

What 'refrains' do the processes of the systems and bodies of the ecosphere 'sing' (Guattari, 1995)? What other tongues do we need to hear in order to renew a livable contract with the world (Serres, 2003)? How are those 'voices' brought into ethics and politics?

"The more we look into ecological controversies, the more important it becomes to consider an ecosystem as a sort of assembly without walls, inside which many types of 'speakers' are allowed to 'have a voice' …. Because it's obvious that the traditional site of politics have moved towards the centre of gravity of ecology. Ecology is not about a naturalisation of politics—as if one wanted to 'treat humans like plants and animals', it's about the recognition of the immense complexity involved for any entity—human or nonhuman—to have a voice, to take a stand, to be counted, to be represented, to be connected with others" (Latour and Weibel, 2005, pages 458–459).

This is not only about "being alive" Ingold (2011) but staying alive. Geography and related disciplines need to be seeking ways of getting the work done differently, and methods such as sonification can play their part in this.

Sonification for geography and beyond

There are a number of contextual reasons why sonification is emerging as an approach. Firstly, there is the volume of intimate data from systems that exists and/or can be easily generated. And *live streams* of data of various types are also becoming more producible through relatively low-cost technology. This might be so for bodies, financial markets, online information flows, traffic flows, and also environmental processes such as weather and tidal flows. If we see bodies, organizations, markets, places, and landscapes as outcome of flows and connections, and the *process*es of ecosocial systems as major agential forces (Barad, 2007), then we can begin to 'hear' these systems working once sonified. Secondly and relatedly, new forms of software–hardware platforms where sonifications can be developed, located, and accessed are becoming 'everyday'.

Data sonification is emerging in geography. *Hear*, for example, Evan and Jones's (2008) sonification-based rhythmanalysis of urban socionatures. In the 'film of the paper' on YouTube,[2] they show visual graphs or urban water course flow, and then play a sonification

of the same data as they discuss the Lefebvre-based assertion that the rhythms of the city "cannot be revealed by images and imaging devices alone" (page 663). They suggest we need to listen, and to synthesize multiple sensory information inputs, in order to become "resensitized" to rhythm (and thus process), particularly those that operate beyond everyday sense due to their location, register, scale, rhythms, and tempi.

There are many aspects of sonification that are of potential interest to geographers. Firstly, it (obviously) creates audio output and, as we know, the human brain receives and responds to audio information differently than to visual information. O'Callaghan (2010) discusses this in his challenging of the 'visuocentric' nature of philosophy and understanding of human becoming. Sounds, he suggests, are experienced as events rather than objects and they have spatial and temporal dimensions as we perceive them.

Secondly, then, as sonifications run through time they retain the liveliness of an event. Indeed, they are an event. Thirdly, given their relationship to music and its temporal/rhythmic characteristics, they might be particularly suited to exploring processes, and within processes, rhythms, tempi which are so critical in getting a grip on the liveliness of places (Lefebvre, 2004). Fourthly, in its ability to express 'hidden' systems, or 'hard-to-perceive' processes, sonification might be particularly useful in not only researching processes of affective exchange and in generating nonrepresentational refrains of relation life (Guattari, 2000), but also ecologies of place, bringing the nonhuman into ontological, political, and ethical play. Ingold (2000) in his essay on the temporality of the landscape discusses issues of attending to rhythms and the benefits of slowing down/compressing time as a means of engaging with "dwelt life" within them.

Interplays between (human) geography and art have grown markedly (Hawkins, 2011). The synthesis of poetics and science at the heart of Lefebvrian rhythmanalysis (Evans and Jones, 2008)—perhaps a "poetic science" (Berthold, 2004)—seems a fertile ground for progress in order to deepen ways in which we engage with interactions of peoples, natures, places, and landscapes. Guattari (2000) turns to the poets rather than to the scientific paradigm (Pindar and Sutton, 2000), for their abilities to render creative engagements with the world's refrains.

Sonification is a process that can interleave natural and social sciences, and artistic renderings of, and responses to, all manners of process terrains, such as bodies and landscapes. Artists are using sonifications in suites of methods to explore processes in nature/landscape. See, for example, the work of Lyons and Piggott (2011) on the River Torridge catchment area where 'ecoides'—flexible environmental sensors—can generate flows of data from hidden processes. Another example is the climate data sonification work of the artist Andrea Polli.[3]

Thus sonification might be of use in all manners of witnessing (Dewsbury, 2003; Lorimer, 2010), sensing (Paterson, 2009), apprehending (Simpson, 2012) ongoing relational (inter-embodied), affective, processes of ecosocial becoming. We feel the novel methodological possibilities of sonification can contribute to current debates on studying practice-related themes (Dewsbury, 2010; Simpson, 2011). Sound has rich potentiality in its materiality (Kanngieser, 2011; Simpson, 2009; Wood et al, 2007) and thus a whole new palette of process registers to engage with is opened up, as is a whole new palette of 'compositional' tools.

Time geography, tempi, registers, and rhythms
In time geography there has been longstanding interest in diagramming and mapping the social in ways that seek to highlight spatiotemporal rhythms and routines, (Edensor, 2010; Evans and Jones, 2008; Elden, 2004; Mels, 2004; Simpson, 2012), and questions of representation/nonrepresentation and rhythm have been discussed by Simpson (2008).

[3] http://www.andreapolli.com

Despite social constructionist type accounts of space and nature which see clock time and social time as floating free from natural rhythms (see Macnaghten and Urry, 1998) a plethora of natural rhythms in fact suffuses through the social: for example, the seasons, day and night, the durability of materials and organisms, tides, human and nonhuman body clocks, as well as longer rhythms of such cycles as sun spots, pole reversal, climatic and volcanic cycles, and of course these bring rhythms and energies.

"As Lefebvre says, '(There is) nothing inert in the world', which he illustrates with the examples of the seemingly quiescent garden that is suffused with the polyrhythms of 'trees, flowers, birds and insects' (2004:17) and the forest, which 'moves in innumerable ways: the combined movements of the soil, the earth, the sun. or the movements of the molecules and atoms that compose it' (20). Certain natural processes are 'only slow in relation to our time, to our body, the measure of rhythms' (ibid). By acknowledging the usually cyclical rhythms of nature: processes of growth and decay, the surgings of rivers, the changes in the weather and the activities of animals and birds which breed, nest and migrate, we can identify the ubiquitous presences of non-human entities and energies in and through place" (Edensor, 2010, page 7).

We thus live in complex temporal ecologies formed of varying and intersecting tempi, velocities, and rhythms embedded in various bodies, materials, and processes (Jones, 2010). But the complex rhythms of things like landscapes and bodies can be hard to appreciate in that they are not easily perceived by human senses and/or are 'other' to human temporality. This is a general epistemological problem, and also a problem in terms of 'managing' nature–society relations embedded in processes such as flooding, drought, and landscape-scale biodiversity management. Wood (2008, page 262) argues:

"Temporal factors are of paramount importance because the degree to which society and nature operate in consonance or dissonance profoundly influences the health of the natural environment, the structure of the social system and, hence, the prospects of sustainable development."

Rhythms, tempi, and registers are critical in articulations of timespace (May and Thrift, 2001) generally, and also in how space is patterned into "ground" (Harrison et al, 2004) which is populated with all manner of formations. As space is patterned, time is rhythmed, thus creating what Jones (2011) has termed "rhythmpattern".

There is an interest here in emergence, where distinguishable forms shape themselves out of a ground, but in essence are still ground. Deleuze (1997) addresses this state of (self-)determination where something "distinguishes itself—and yet that [its ground] from which it distinguishes itself does not distinguish itself from it" (page 28). This echoes Nietzsche's and other philosophers' views that being and becoming are inseparable, becoming is merely the patterning (and rhythmicizing) of being, a self-driven individuating process that conveys to us the idea of life itself.

The multiple rhythms running through rhythmpatterns of places and landscape can have differing tempi, durations, and types of sequences in varying combinations. Tides are powerful examples of this. They comprise complex sequences of sea-level rise and fall, and related currents, driven chiefly by the gravitational pull of the moon and rotation of the earth in conjunction with a whole host of other factors, including solar gravity, and coastal and seabed topography. Tides bring distinct and varying rhythms to coastal areas across the world, which vary in detail right down to the hyperlocal (harbours only a short distance apart might have tidal range and timing differences critical to practices such as inshore fishing). The local rhythmpatterns of sea-level rise and fall and exposure and inundation of intertidal areas, in turn, are geared in complex ratios with the diurnal and seasonal rhythms to create intricate local rhythmpatterns of ecosocial becoming.

Tidal processes and rhythms (Severn Estuary): arrhythmias, polyrhythmias, and eurhythmias

The Severn Estuary forms the sea division between southwest England and southeast Wales and the coastal edge of eleven local authority areas. It is some 557 km², with 18% of this being intertidal (100 km²). It is macrotidal (Haslett, 2008), having the highest tidal range in Europe and the second highest in the world, with the sea level rising and falling by as much as 14.5 m (Avonmouth) in the space of 12 hours at the highest tides. Approximately 80% of the estuary's 370 km shoreline is lined with sea defences which stop the very highest tides flooding low-lying surrounding land. These are in many places openly accessible, and used for agricultural and recreational purposes, and accessing/viewing the intertidal areas.

Generated by the never-ending gravitational *pas de trois* of earth, sun, and moon, the tidal rhythms are a key part of the aliveness of this landscape in process terms, creating huge, ever-morphing vistas of shore, intertidal areas, sea, sky, space, and light, and shaping elements of its physical features, ecology, economy, and culture in terms of spacetime rhythms. The higher tides wash up the tidal reaches of a number of major rivers (through urban centres) that drain into the estuary. In the river Severn this creates the Severn Bore, a tidal wave that runs back up the river to above Gloucester. This entire rhythmic spectacle is ecologically and culturally significant and attracts residents, tourists, surfers, and artists.

The tides are entangled with a multitude of materialities/practices, which include transport, recreation, conservation, archaeology, rambling, birdwatching, and beach tourism. These have complex temporal rhythms geared to the multiple sequences embedded in tidal cycles. The main sequences are the daily rise and fall of the tide in a semidiurnal rhythm (tide rising and falling roughly twice in 24 hours); the monthly (lunar) cycle which shows a progression from spring to neap tides in response to the phases of the moon; and the seasonal (yearly) sequence of the tidal ranges which respond to the relative positions of the planets (eg, spring tides at the equinoxes). It is important to note that, firstly, these sequences do not correspond to the more ubiquitous hourly, daily, and monthly grids in any simple ratio and, secondly, that the precise heights and times of tides vary with local conditions such as wind speed and direction, atmospheric pressure, and the amount of fresh water issuing from the rivers.

Some 3 000 000 people live around the estuary (Barker, 2008) in large urban conurbations and remoter rural settlements. The management of the estuary and its margins poses considerable challenges due to the highly dynamic nature of the tidal systems. The reach of the estuary across local and national legislative boundaries, and the many competing ecosystem services the tidal flows bring compound this complexity. A set of sometimes conflicting demands is placed upon the tidal estuary: for example, between recreational use, resource extraction, nature conservation, waste discharge, agriculture (grazing of salt marshes), transport needs, coastal management and development, and public access. There are significant pressures on the tidal Severn, and its intertidal areas and ecosystem services, as there are on estuaries and delta areas worldwide.

Barker (2008) suggests that the communities who live around the estuary (especially those in large conurbations) have "lost touch" with the tidal/estuarine landscape and its rhythms as technologies, work, transport, and lifestyle practices have changed. For example, tide-determined ferry schedules have been replaced by large road bridges. The large ports around the estuary were, for centuries, tidal ports in the heart of the cities, with their working and commerce patterns tide-determined rather than day–night-determined; then the ports were made nontidal; and then new dock facilities were built taking them away from city centres. Many smaller tidal harbours, which were hubs in busy coastal trading routes, have now closed.

Lefebvre (2004) describes four alignments of rhythms—arrhythmia, polyrhythmia, eurhythmia, and isorhythmia—which together represent a range of dissonance or consonance between rhythms and the varying consequences of such. We feel examples of these, particularly the first three, abound in and around the tidal landscapes.

Today local residents not connected to the tidal estuary by work, leisure, or casual acquaintance of locality may only occasionally experience a clash of tidal and diurnal rhythms, such as a swing bridge disrupting rush-hour traffic as a boat passes into port. Some cities might be at risk of flooding if high rainfall coincides with high tides (arrhythmia). Farmers who get the benefit of grazing livestock on the salt marshes will, on occasions, have to ensure their livestock is moved to safety at the very highest tides (polyrhythmia). Visitors to this landscape might notice the coming and going of birds, birdwatchers, and pleasure and commercial sea crafts, and other travelers that are timed to *make the most of the tides* (eurhythmia). These characterizations of rhythms are initially useful, but we feel are not a sufficiently subtle and flexible framework to deal appropriately with the complexity of the rhythmic exchanges between inhabitants and landscape. The potentiality of sonification is to interweave rhythms of these types into accounts that engage with the complexity and interchange between them.

There might well be hints of romanticism in these concerns to reconnect community with the processes and rhythms of natural landscapes, but not only does they chime with local environmental governance trajectories, as hinted at above, they chime with numerous eco and materialist philosophies and also concerns for the problematic overwriting of the cyclical in everyday life by the linear as considered by Lefebvre (see Simpson, 2008). To return to the eradication of refrains, tidal processes can be seen in this sense:

"Rhythmanalysis has the power to perform a similar critique of the effects of capitalism on socio-nature as it does on the purely social life world, revealing rhythms that are being progressively homogenised by the process of development and destruction. The rhythms of birdsong are removed by the process of brownfield development, which infills sites that are used for feeding in densely built-up urban areas. Similarly, a river that has been culverted, or put underground, will have had its rhythms changed dramatically, with a far more pronounced flow regime. The rhythms of its meanders, which strike a balance between local topography and precipitation, have been stunted in order to constrain its floodplain and free up space for development. Listening to the regimes of urban rivers over the last 200 years would produce a pronounced effect on the listener, as intensity and noise levels increase. Similarly, charting the meander and sinuosity ratios would reveal a shortening of rhythm, as the modified river tended towards a value of 1" (Evans and Jones, 2008, page 664).

Reconnecting local communities to landscapes and geomorphological processes is an important aspect of developing resilience and sustainable management (Cabinet Office, 2008). Under the UK Flood and Water Management Act 2010, local authorities are responsible for managing the risk of local floods (groundwater, surface water, and ordinary water course flooding). One important step in meeting those demands is to develop better understandings of local water issues with communities in order to support effective decision making and behaviour change. This is how one organization puts this:

"We believe a deeper connection to local water bodies can bring a new cycle of community hope and energy that will lead to healthier urban waters, improved public health, strengthened local businesses, and new jobs, as well as expanded educational, recreational, housing, and social opportunities" (Urban Waters Federal Partnership 2011).

Sonifications of tidal and other rhythms/processes in the Severn Estuary

Landscapes are "polyvocal, dynamic, cultural processes" (Maddrell, 2010, page 138), but we argue that such polyvocalism needs to extend to nonhuman, ecological, processes and their rhythms. If, as Barad (2007, page 141) states, "the primary ontological units are not 'things' but phenomena—dynamic topological reconfigurations/entanglements/relationalities/(re)articulations of the world", we need ways of engaging with the polyvocalism of landscape as manifestation of ecologies of processes.

Differing human senses are tuned to differing manifestations of timespace. Music, which is fundamentally about rhythm (sonic temporal patterning), shows us that hearing is a key means of perceiving patterns of/in time. Thus turning various system rhythms that are inaccessible to human perception—either because they are outside the human hearing register, and/or operating in time durations beyond habitual perception—into sound, music even, can be an important way of engaging with them.

A software artefact that sonified the tide at Avonmouth (see figure 1 and online at http://www.digital-arts.org.uk/tide.htm) was introduced 'face-to-face' to members of the public attending the Bristol Festival of Nature, 2010. In this Avonmouth prototype a number of important decisions as to data sources, sonification methods, and sound design had to be taken, which makes it a useful candidate for a case study. This artefact eventually became the catalyst for a developing a multifaceted body of work, created in collaboration with University of the West of England music technology students, who produced further data-inspired sonifications and compositions of various social and ecological phenomena of the Severn Estuary. Audio examples of this newer work (figure 2) can be found at http://www.sonicsevern.co.uk.

In sonification parlance, the process of finding and applying sounds to communicate complex processes and rhythms is called 'mapping'. It is one of the key steps that decide on whether and how relationships within and between data sources can be perceived by its listeners. The reference to a 'map' may be due to the sound designer's need to graph out how the artful crossover from quantitative measurements to sound perception is attempted.
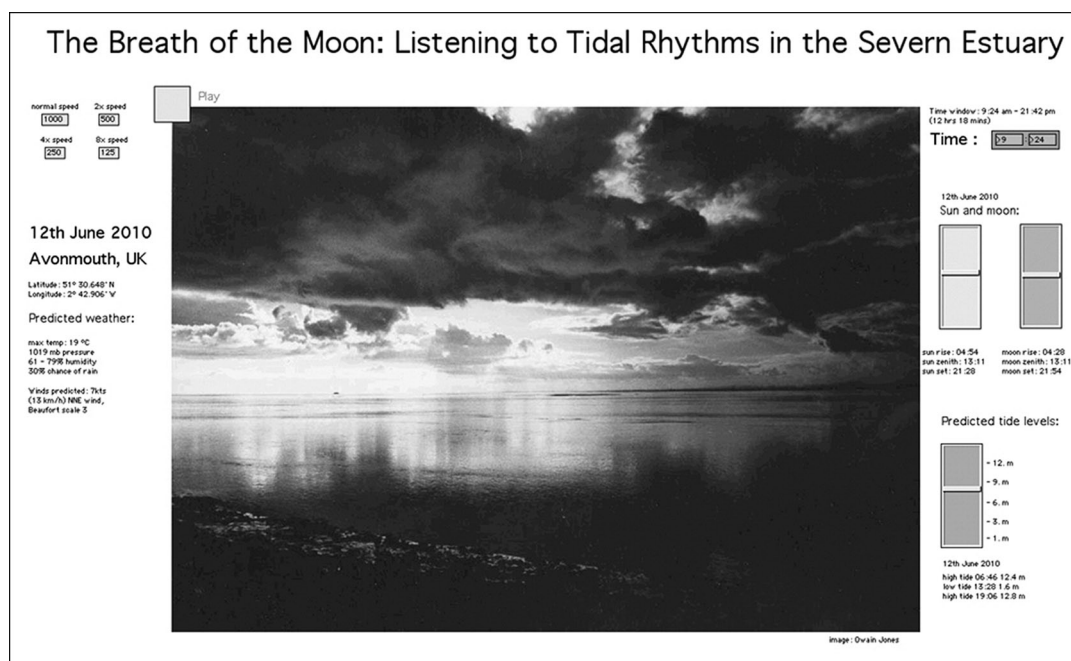
Figure 1. Screengrab of the software interface of the Avonmouth prototype, 2010. Code, design, and photographic media by the authors. Copyright by the authors.
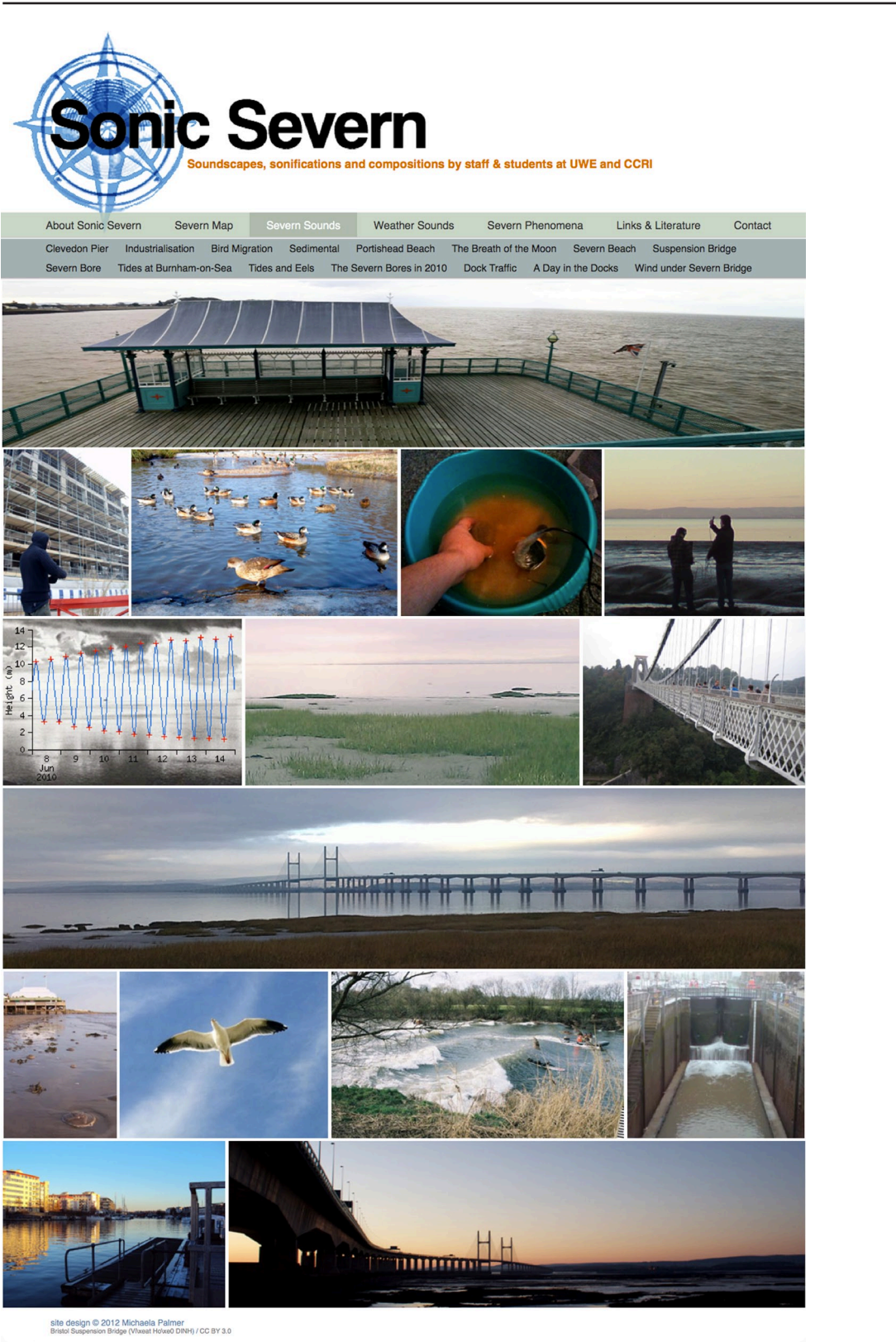
Figure 2. [In colour online.] Sonic Severn web platform (each image is a link to a sonification or sound composition). Site design copyright by the authors and participating students.

A sonification artefact/event is often easier to listen to if it allows listeners to merge qualitative and quantitative aspects, lived experience and observation, which also represents the basic principles of how humans map out landscape: by measuring and calculating it, but also by experiencing it.

Yet experience is an inaccurate map. One moment, the estuary's wind sandblasts the body, shoves the hair about, and forces tears from the eyes; sand blows into mouth and ears; and the drizzling rain sticks it all together. The next moment, feet still sinking into the mud, we catch ourselves describing our sojourn in the estuary to an imaginary dialogue partner as if it was already in the past. How smoothly experience can morph into internal storyline-weaving. Are we only really experiencing when our continuous process of interpretation encounters unforeseen ruptures between experience and expectation: as, for example, in setting out on a recording trip to Severn Beach—perhaps in the hope to capture seagulls, waves, and small boats—only to find a vast open space full of wind, industrial noise, and traffic. An encounter like this may seem disappointing but has the potential to initiate a refreshed and more critical engagement with what we are actually immersed in. The opportunity arises to experience more intensely, and *what we find then* does not lend itself to being easily communicated.

But quantitative estuary maps can be equally flawed. For example, the Severn has one of the best-described sedimentary regimes of any estuary in the world (Kirby, 2011). Thirty million tonnes of fine silt are suspended in the estuary's waters during a typical spring tide, but not equally: research revealed that there are areas of denser and less dense suspensions, some suspensions remain at fairly specific locations within the estuary; others move about quite unpredictably with the changing neap and spring tides (Kirby, 2011). Moreover, the amount of moved material depends on the severity of the tide, a process that contributes to the constant redistribution of the landmass. Thus research—as well as first-hand observation—tells us that, in this intertidal environment, a simple distinction between elements—water and land, salt water and fresh water, water and materials carried in it, is quite misplaced: here they all permeate each other. Static representations of the coastline, high-tide and low-tide markers and the like, cannot fully capture that what is in-between, what is forever in a process of flux.

Since both experiential and quantitative maps have their shortcomings, it is worthwhile considering what new perspective a sonic map of the estuary could add. An advantage of sonic representations is that their temporal nature has a natural relation to rhythmpatterns and makes for a flexible mapping material. Thus a sonic map could redraw itself in time, in step with the tide, while still allowing for the sensation of site-specific estuary sounds, like the seagull colonies on Flatholm. Such iconic sounds carry a great deal of information about the physicality and materiality of a location and its sounding objects (Gaver, 1993), which helps to 'ground' listeners. To explore the map, listeners would need to interact with it in some way. Perhaps by moving horizontally, listeners could hear sounds within a certain range of their position, like one would do on sound recording trips. Movement would thus encourage discovery via comparative listening—for example, the discovery of different wave sounds caused by a different bathometries in the estuary: at Clevedon seafront one might hear small waves rushing onto a pebble-covered bay, while at Burnham-on-Sea the wide-open sandy flats produce only occasional water ripples. To further an understanding of the interdependence of the environmental processes in the estuary, the sonic map would need to be scalable in dimension and time, as this allows for synthetic listening (listening to the estuary as a whole), and also need to make new connections between certain sonified data streams: for instance, between lunar zenith and its following high tide, or between wind conditions and tide height. Such an interactive sonic map would be an enormous undertaking that could only be approached step by step. The Avonmouth prototype (discussed in the following) can only be a first small part of it. Nevertheless, the investigation of its methodology

is useful, since a larger artefact would build on the decisions made and the problems solved in the prototype.

Data mapping methodology used in the prototype

Whether a sonification event communicates successfully depends on the acoustic perception of its listeners and on its mapping, and in the field of sonification it is recognized that mapping cannot usefully apply an empirical approach, but requires a semiotic approach that reflects both listening context and intended listeners. Mapping can therefore be understood as a "representation continuum", ranging from analogic (intrinsically related) to symbolical (arbitrarily related) sounds (Kramer, 1994). Successful communication via sound thus depends much on the expertise of the sound designer as well as on the feedback of a test audience. Yet it has also been pointed out that the musicality of a sonification (as opposed to using pure sine wave tones, etc) is significant, as it facilitates ease of listening, which in turn helps listeners to correctly interpret what they hear (Vickers and Hogg, 2006).

With this in mind, the main technique chosen for the Avonmouth sonification was parameter mapping (Scaletti, 1994), which means that changes in numeric data streams affect changes in the parameters of the sounds (that represent these data). Thus by interpreting audible differences (perhaps in onset, pitch, duration, or amplitude of a sound), a listener is able to 'hear' what sort of processes take place in the data. A known disadvantage of parameter mapping is that listeners need to know exactly how the data relate to the sound before they can correctly interpret what they hear (Hermann and Ritter, 2004). However, this learning requirement can be lessened considerably if the sounds are mapped intuitively and consistently. For example, in the Avonmouth artefact, the water of the flood was represented by a mass of musical notes whose duration and interduration intervals were shortened in time with the rising tide to give the impression of a gradually faster moving and intensifying musical body.

But for multidimensional data like the Severn Estuary data, parameter mapping can quickly become complex. Since human memory is limited—our short-term memory can hold only about seven items of information at the same time (Miller, 1956)—it is impossible to follow a large number of changing sounds without losing track of the sonification as a whole. Listening to too many data streams from the estuary would have made the cyclical nature of tidal sounds—as well as their interrelations—no longer perceivable. Hence in the prototype, only three data streams were mapped: the level of the tide over the mean sea level; weather data (wind speed and direction); and the solar–lunar constellation. These three kinds of data were mapped to three groups of sounds, each with a distinct timbre. Changes within the data could be communicated by altering some of the parameters within its sound group (onset, duration, decay, pitch, etc), and yet its overall timbre would remain constant and thereby identifiable. This strategy encourages comparative listening, a mode in which the specific local conditions (variations in the data) can come to the fore. To increase the intuitive attribution of sound to data source further, and to aid the comparative listening process, some sound metaphors (increased presence of sounds = swelling of a water body) or self-labelling sounds (wind sounds = wind data) were used.

The tidal data were represented by synthesized bell sounds. This choice may initially seem counterintuitive, but the wave-like swinging motion that creates the sounds of real bell-type instruments was relied upon to act as a conceptual bridge to the wave motion of water: one might associate larger waves/bells with lower sounds, smaller waves/water ripples with higher pitched and more polyphonic sounds. The bell sounds were synthesized within the programming environment Max/msp and tuned to a Pythagorean scale, so they would harmonize with each other when rung in a random order but without suggesting a chord progression or distinct melody that would distract listeners from hearing important data changes. The bell sounds

were created by using frequency modulation and, to avoid listening fatigue, by randomizing some of the bell-sound partials.

The weather data focused primarily on the wind conditions forecast for the day: 7 kts (13 km/h) north–northeasterly wind, Beaufort scale 3. This equates to a gentle breeze where leaves and small twigs would be moving and flags would be extending. On the sea one would see some larger wavelets but only a few white crests. Considering the wind data of 12 June was important as they helped to predict the character of the coming tide. The funnel-shaped Severn Estuary extends from a south–southwesterly to a north–northeasterly direction, with south–southwest being the predominant wind direction. The north–northeasterly wind predicted for 12 June would have enforced the receding tide, and slowed down the incoming high tide by a small degree. This is why in the artefact the 'wind sounds' become more audible as the tide goes out. To allow for an intuitive interpretation of these sounds as wind, sound samples, and synthesized sounds (created via noise filters and convoluted sustained bell sounds) were combined, and added as another layer to the receding water sounds.

The 12 June 2010 was chosen not only because it coincided with the Festival of Nature where the artefact would be exhibited, but also because on this day there was a new moon. When sun and moon are on the same side of the earth, their gravitational forces combine. At these times, the high tides are especially high and the low tides are very low, creating the so-called spring high tides/low tides. Since the sun's gravitational force on the earth is about 46% of that of the moon, the position of both celestial bodies is important in order to predict the strength of the tide. On 12 June, the north–northeasterly wind enforced an already remarkable spring low tide. For this reason the sonification placed special emphasis on enhancing the listening experience during the receding tide. As an effect of the celestial constellation, the duration of the bell sounds would gradually extend, and a flanging effect (a sound delay of <20 ms, adding a 'whoosh' to the sound) would come in, creating an increasingly eerie atmosphere. Combined with the wind sounds, this enforced the sonic suggestion of a vast open space and was added to help listeners to intuitively perceive that this low tide was a special tidal event.

Since the Avonmouth prototype sonified only one tidal cycle, it was decided that the influence of solar and lunar force would become only indirectly noticeable. If the artefact were to be extended (to sonify the tide of a full month, for example), a more direct sonic representation of solar and lunar path would become necessary.

Data window and suggested sound journey
The prototype used the data points for interpolation (shown in table 1). The time window for the sonification was set as 9:24 am—21:42 pm GMT. This would stretch across 12 hours and 18 minutes, or 738 minutes. This window would allow the sonification to start mid-tide, fall to low tide, rise to high tide, and then end once the tide had again fallen back to the starting point; so, in other words, one full cycle had been sonified. From a listener's point this allows for a fairly interesting sound experience as the first part leading to low tide is reached quickly, then there is a longer build up to high tide where the piece exceeds the starting point, and then finally the return to the beginning brings the piece to a close.

Table 1. Data for the port of Avonmouth 12 June 2010 (source: National Oceanographic Centre, 2012).

Moon rise: 04:28	Moon zenith: 13:11	Moon set: 21:54
Sun rise: 04:54	Sun zenith: 13:11	Sun set: 21:28

Predicted tide height for Avonmouth 12 June 2010:

High tide: 06:46 12.4 m	Low tide: 13:28 1.6 m	High tide: 19:06 12.8 m

The sound journey begins with a mix of ambient, recorded sound samples that were looped to evoke a feeling of situatedness (water lapping). This is useful as recorded sounds already carry a great deal of information about the physicality and materiality of location and their sounding objects (Gaver, 1993). With the receding waters the duration of the bell sounds extends, and their reverberation increases, suggesting a wide-open, empty space, supported by trailing wind sounds. The sonic experience of low tide is thus fairly abstract; especially since any all-too-literal sound markers were here neglected. Then with flooding waters the bell sounds ring shorter, with shorter interduration intervals. This creates more sound overlaps, suggesting a faster movement of waves, combined with larger wave sounds. The piece ends with water lapping.

Developing the sonification through user feedback
The development of the Avonmouth prototype—described above—has also been shaped by listening experiences. For example, at the very first conceptualization stage three decisions were taken, two of which were later overturned by listeners' feedback. These decisions were to reduce the number of estuary data sources to a few, to sonify the tide in real time (not time-compressed), and to largely neglect data visualizations.

Early prototype testing with a small group of users soon revealed that the restriction of data sources was useful (these participants could easily identify and follow different data sources by listening), but the larger tidal cycles were difficult to perceive, and the lack of data visualization made the artefact not very intuitive to use. The last two points had to be addressed prior to introducing the Avonmouth prototype at the Festival of Nature to the public.

The difficulty of perceiving tidal changes relates to our expectations of duration and rhythmic repetition. The scale of real-time tidal events does not sit comfortably with our habitual listening modes: for reasons of survival, humans pay attention to sound events with high sound levels and accents (waves crashing into a seawall), but tend to ignore long-drawn-out processes with little change of rhythm and dynamics (a receding tide revealing mud flats). Only if we were to habitually listen to long-drawn-out processes could we eventually hear their rhythms and understand them as living processes extended in time.

The Avonmouth tide, a duo-diurnal rhythm that reaches the end of one basic unit of time (or beat) after 24-or-so hours, is such a process. Interpreted as a rhythmic composition, it would fall into a 'macro-timescale' of musical architecture, which is measured in minutes, hours, or days (Roads, 2001, pages 3–4). The relative positions of earth, moon, and sun on the other hand repeat themselves only every nineteen years or so, a rhythm which corresponds to a 'supra-timescale', covering months, years, decades, and centuries (Roads, 2001, pages 3–4). Since neither timescale coincides much with our habitual experiences of rhythmic compositions, only someone who regularly steps beyond their usual listening modes would be able to perceive, say, the rhythm of a monthly spring–neap cycle, or the annual tidal cycle.

Weather patterns, on the other hand, fall into the everyday experience of duration, but are characterized by arrhythmic repetition; indeed, strong gusts of wind, or rainy days with sunny intervals are quite common in the estuary. Therefore a further difficulty for nonspecialist listeners was to perceive the connections between the seemingly chaotic weather patterns and the seemingly regular tidal patterns. To aid listeners in this task, it was decided to scale the data before playing them back as sound. The real-time window of 738 minutes was converted into 738 metronome counts, one count initially representing one minute of real time. By increasing the metronome speed it was then possible to compress the tidal cycle into shorter and shorter periods of time, whilst still maintaining the characteristics of the data. Thus, although the real-time sonification aspect was now lost, the tidal rhythmpatterns

and the relationships between their data sources could became more transparent. Listeners at the Festival of Nature, who could choose from eight such time-compression presets, initially preferred the higher compression rates but, as if listening out for more details the second time around, then often changed to a less compressed rate that would re-extend the piece for them in time.

The second point that needed addressing was to interrelate the data more intuitively. To underline the connections between celestial and tidal data, a tidal prediction graph (see figure 3) and two astronomical tables were read into Max/msp and translated into vertical sliders. These sliders visualized tide height, sun rise and set, and moonrise and set, and allowed audience members to observe the movement of sun, moon, and tide whilst hearing the sounds change. This allowed for a more intuitive understanding of the processes in question. Moreover, new connections could be made; for instance, the connection between solar/lunar zenith and its following high spring tide could now be seen and heard.

With the data scaled, time-compressed and (some of it) visualized, for most listeners at the Festival of Nature the interrelations between the three data streams became apparent; in other words, when all three data streams fell into the habitual human reference frame they could 'easily hear what was going on'. Indeed, within the habitual human reference frame, we have developed a high sensitivity for structured motion (rhythm) and patterns, and it is this that allows us to perceive things afresh. Thus the key point confirmed at the Festival of Nature was that a shift of timescales can open the door to new insights. This resonates with Lefebvre's observation that

> "Our scale determines our location, our place in the space–time of the universe: what we perceive of it and what serves as a point of departure for practice, as for theoretical knowledge …. Another scale would determine another world. The same? Without doubt, but differently grasped" (Lefebvre, 2004, page 83).
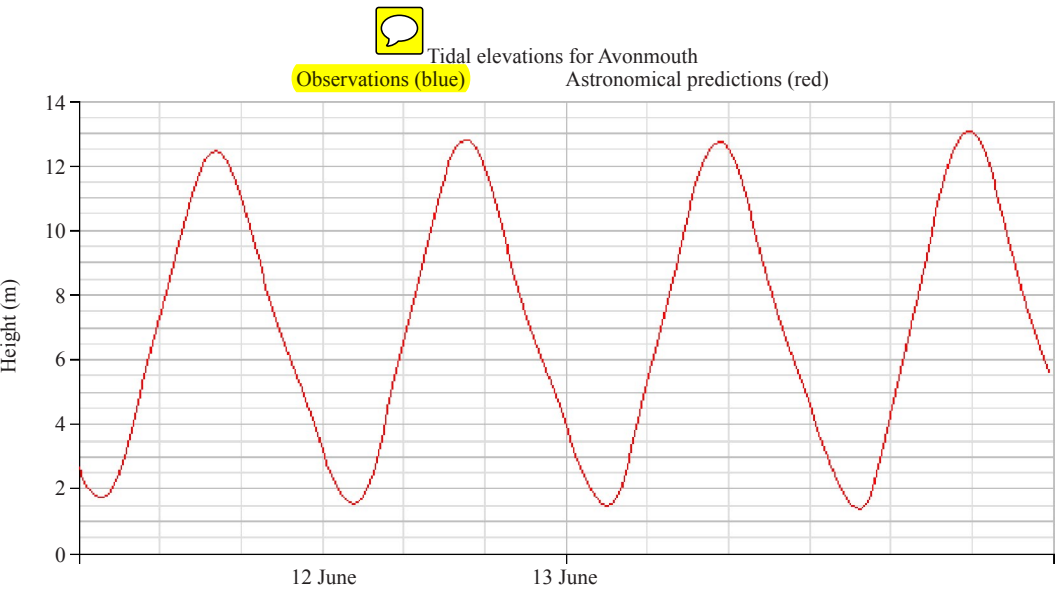
Figure 3. [In colour online.] High and low water times and heights for Avonmouth 12 and 13 June 2010. Copyright: National Oceanographic Centre. Permission granted.

Sonification and the politics of mapping

The Severn sonifications use well-known sonification tools, like parameter mapping, sound grouping, and data scaling as envisaged by Kramer et al (1999). However, there were also some methodological differences that raised questions about the sonification process itself.

Recently it has been demanded that, within a scientific context, sonifications must reflect objective relations in the input data, use systematic means to translate the data into sound, and should be set up in such a way that they are repeatable and reproducible (Hermann, 2008, page 5).

This raises a couple of questions; one of which is whether the data-driven sonifications may be called a sonification in the scientific sense. What is often criticized about artefacts is that their algorithms are not made transparent, and so it remains unclear whether the sonification was carried out objectively and systematically. It is true, however, that a sonification of data merges qualitative and quantitative information, as it already involves the perception of the researcher who maps data to sound. Moreover, for a sonification to communicate successfully to its listeners, it can be necessary to make certain patterns in the dataset more easily recognizable than others. This means altering the mapping in such a way that listeners' attention is drawn to these patterns, and by doing so adding a layer of interpretation. Thus, rather than attempting to eliminate the role of perception and interpretation in a sonification, it seems more helpful to acknowledge and discuss their roles.

The second question is one of taking field conditions into account: while perceptive mapping processes are rarely 'accurate', neither are the (quantitative) data available. In the case of a Severn estuary sonification, for example, the problems start with the sheer size of the estuary and its area of influence. As they are part of larger (aquatic and littoral) ecosystems and catchment areas, it is difficult to define the boundaries for estuary data streams; and local weather conditions measured on the ground are often merely effects of changes caused somewhere else in the system. An additional complication is that much publicly available scientific field data are still not available in real time, making the sonification input look comparatively coarse. Like a chain that is only as strong as its weakest link, data quality, processing capacity, and mapping strategy must be adequately balanced in order to arrive at a pragmatic solution.

When mentioning field conditions, Lefebvre's (2004) rhythmanalysis once again provides a useful prompt: firstly, because a rhythmanalyst's frame of reference forms an important part of the research and, secondly, because it links a researcher to a geographical location where the observation of rhythms takes place. Yet this concept is not unproblematic either. In the "Rhythmanalysis of Mediterranean cities", Lefebvre introduces the notion of "lunar towns of the oceans", and "solar towns of the Mediterranean" (page 91), because of the powerful tidal refrains of the former and the stronger solar refrains of the latter. This distinction certainly works at some level, but a historical and hybrid perspective is likely to be more productive.

(Historical) rhythmanalysis of the settlements around the Severn estuary would certainly reveal how the influence of tidal rhythms has been engrained into their fabric, culture, and economy. However, it would also show that today's estuary inhabitants might be guided more by diurnal than by lunar rhythms. It might be fair to say that, for some, clock time is no longer perceived as fragmenting local lunar rhythms, but that lunar rhythms now inconveniently interrupt diurnal rhythms via bridge closures, inconvenient road layouts, or irregular work times. In lunar towns of the oceans, do rhythms (still) clash? An interesting question in many ways, not in the least because only a *participant* observer could answer it.

Sonification, and related sound art constructions, can play a part in reconnecting the communities that live around the estuary's shores, and other stakeholders, to this dynamic landscape by letting them hear its living rhythms in more accessible forms than their actual space–time registers. This relinking of communities to their watershed rhythms (be they tidal, flood, or drought rhythms) is considered by a range of agencies as a necessary step in developing local resilience and contexts for effective environmental management in the face

of a series of challenges which include climate change, flood risk, large-scale development, and changing marine and terrestrial governance structures which are impacting so negatively on this and other estuarine environments.

Conclusion—breathing and geography

Those observing the tides before Newton's revelation of gravity struggled (understandably!) to explain the extraordinary ebb and flow of the oceans' levels and margins. But some had the sense that it was some rhythmic physical process linked to the moon—a process akin to breathing:

> "As the moon passes by without delay, the sea recedes and leaves the outpourings in their original state of purity and their original quantity. It is as though it is unwittingly drawn up by some breathings of the moon, and then returns to its normal level when this same influence ceases" (*Opera de Temporibus*, Section XXIX, The Venerable Bede, 703 AD).

Tides have also been referred to as the pulse of the earth (Clancy, 1968). Are such metaphors anthropomorphic or do they effectively capture that bodies and landscapes are the outworking of rhythmic processes?

There are approximately 12 000 resting human adult breath cycles to each Severn tidal cycle. However, counting thousands of breaths in order to grasp the nature of the tide is not intuitive; the difference between the two durational scales involved is simply too great. If, on the other hand, the observer is encouraged to mentally switch scales, and observe how, like the tide, each breath unfolds slightly differently each time; how it naturally accelerates, decelerates, pauses, and turns direction, then an intuitive link can quickly be made. Indeed, the breathing metaphor allows us to explore some of the more complex phenomena like fluctuations, flow restrictions, or pauses after the in- breath and out-breath (slack water); in this way almost allowing the observer to perceive these phenomena 'from the inside'. When a sonification artefact subliminally calls on the everyday experience and corporeal memory of its listeners, it can initiate deeper levels of experience, and really strike a chord with its listeners.

As each tidal cycle in the Severn estuary unfolds, the differences within each repetition become perceptible to various means of observation and recording. Thus there is regularity and novelty in complex relation. This is, in a sense, a basic characteristic of (interacting/evolving) human/nonhuman life that includes combinations of cycles (repetition) and novelty. The tidal cycles and their variations will be important to, and perceptible in differing ways to, differing observers. Those who live and work with the tides might immediately notice and recognize some of the differences, but whole levels of detail will still remain hidden, even from their view.

We suggest that sonification can be valuable (methodological) practice for all sorts of terrains that are rhythm-rich, in what we call rhythmpatterns. From bodies to landscapes these are essentially rhythmic entities. How to 'represent' that? How to think of time and space together rather than in separation (Adam, 1998; May and Thrift, 2001)?

Sonifications can not only express the rhythmicities of such 'terrains', they can show both common ground and conflict ground between them. We can begin to think of the data of his/her basic bodily functions (repeating waves, impulses like breathing or the heartbeat) in relation to others. Our bodies live through rhythms; so do landscapes and other systems such as ecosystems. By listening to the refrains perhaps we can begin to hear the other voices, pulses, and life forces of the world. We can maybe even see life in different terms. Recently James Lovelock (in Ferguson, 2009) has said that the definition of life that underpins, and emanates from, biology is far too narrow. Systems live (and breathe) differently. We need to learn to listen to that breathing.

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